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Towards Flexible Lightweight Strain Sensors with Low Temperature Coefficient of Resistance

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Abstract

Covering polycarbonate films with the strain sensing molecular metal α-$(BEDT\text{-}TTF)_2I_3$ [BEDT-TTF =bis(ethylenedithio)tetrathiafulvalene] was studied at different temperatures. It was shown that depending on the temperature of the covering process the conductive strain sensing layers demonstrate different electric transport properties: they vary from metallic to semiconductor-like temperature behavior. However, the electromechanical properties of all films reveal the same strain sensitivity with gauge factors about 10. This result permitted engineering highly strain sensing films with a very low temperature coefficient of resistance (TCR). Therefore, both of the electric and electromechanical properties of these bi layer (BL) films make them very attractive as flexible, durable, low-cost, all-organic strain (pressure) sensors that are able to replace conventional physical sensors in biomedical high-tech.

Keywords: organic molecular metals; conducting bi layer film; metallized polimeric films; gauge-factor

1. Introduction

The application of flexible lightweight sensors in electronics is a key point in the development of high-tech [1]. A simple covering process of polymeric films with highly strain resistive polycrystalline – layer of an organic molecular conductor has been developed [2, 3]. The preparation of light and flexible organic materials that respond rapidly and reversibly after being submitted to tiny stresses promises great opportunities in the field of strain sensors. It is well-known that single crystals of molecular conductors,

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consisting of ion-radical salts (IRS), exhibit striking conducting properties and that such properties are affected under applied pressure [4]. Thus, it has been reported that conducting single crystals of IRS derived from BEDT-TTF exhibit dramatic changes in their conducting properties under isostatic pressure or uniaxial strain. In order to exploit practically the conducting properties of TTF-based IRS, composite BL films based on polycarbonate (PC) with a conducting topmost layer of an organic molecular conductor based on BEDT-TTF were previously reported. We have shown that these BL films may have a great interest for sensor engineering due to important material properties, such as conductivity, high strain (pressure) sensitivity, excellent elasticity, weightless and biocompatibility [3,4]. Here we show that covering layers based on the α-$(BEDT\text{-}TTF)_2I_3$ molecular metal, revealing gauge factor 10, can be prepared with different TCR.

2. Preparation of Humidity Sensing Films

The developed covering process of a polycarbonate film with the α-$(BEDT\text{-}TTF)_2I_3$ molecular organic metal is a very simple two steps procedure; at the first step the films of about 25 µm thick with a 2% wt. of BEDT-TTF have been prepared, at the second step one of the surfaces of films was exposed to I_2/CH_2Cl_2 vapours (Fig.1). The surface of the film easily swells under this treatment that facilitates migration of BEDT-TTF molecules from the bulk film to its swollen surface where they are oxidized by iodine. This redox process induces the rapid nucleation of the α-$(BEDT\text{-}TTF)_2I_3$ metal, with a consequent formation of the conductive strain sensitive topmost layer.

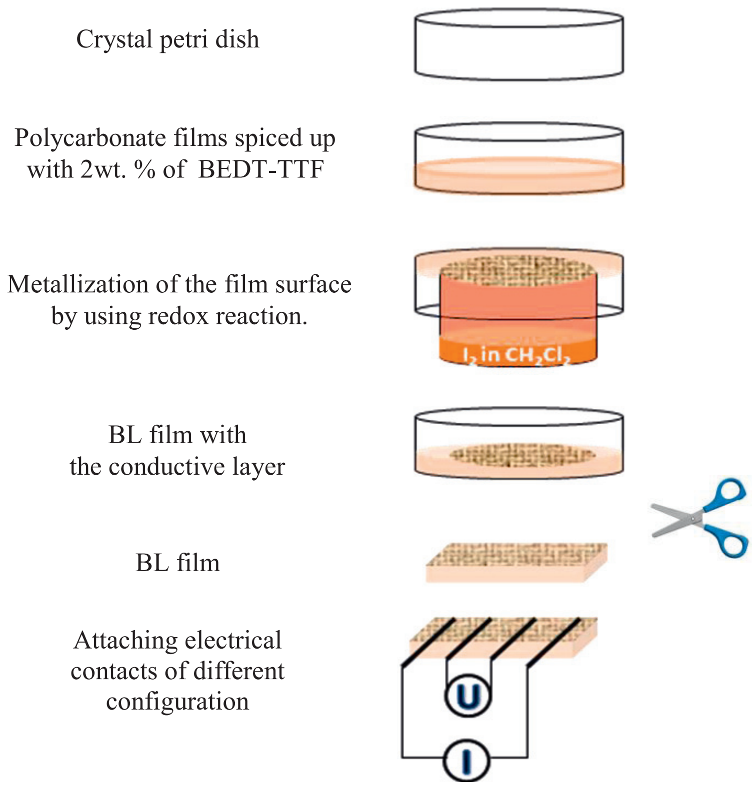

Fig. 1. Scheme of the BL film preparation

In this work we studied the relationship between the properties of the covering layer and the temperature of layer formation. The set of BL films that were covered with the α-$(BEDT\text{-}TTF)_2I_3$ organic molecular metal at different temperatures have been prepared; the temperature varies in the range 7^o -35 ^oC. The composition and texture of the conductive layer based on the α-$(BEDT\text{-}TTF)_2I_3$ metal were studied using powder X-ray, EDX and SEM analytical methods. Fig. 2 shows that the texture of sensitive layers strongly depends on the treatment temperature: the linked crystallites formed at 7 ^oC are nanoscale whereas the metallic layer of α-($(BEDT\text{-}TTF)_2I_3$ prepared at 33 ^oC is formed by submicro crystallites. (Fig. 2)

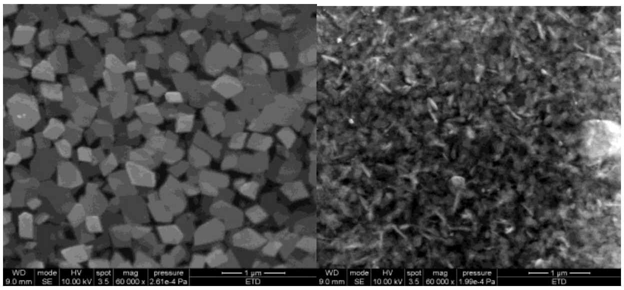

Fig. 2: SEM images of the BL films covered with α-$(BEDT\text{-}TTF)_2I_3$ at different temperatures: 33^{o}C (right), 7^{o}C (left)

The relationship between electrical resistance of the conductive covering layer of the α-(BEDT-TTF)2I3 and its X-ray peaks intensity have been also studied. We found that there are some barriers after that the increasing in the thickness of polycrystalline layer of organic molecular metal (we control it by the intensity of the peaks in the X-ray diffraction), but it does not result in the increasing in the surface conductance of BL film.

3. Electrotransport properties

Temperature resistance dependence of BL films (macroscopic transport properties) were measured using a standard 4-probe dc-method. Rectangular pieces of ca 4.5x2.5 mm^2 were cut out from the film samples and, subsequently, four annealed platinum wires (20 μm in diameter) were attached to the conducting surface of the film sample using a conductive graphite paste. For the deformation experiments an electromechanical positioning system, Parker Actuator 401XR, with a Compax3S Servo Drive System, was equipped with two clamps for film mounting. This system was connected via serial bus (COM) to a computer. The film resistance was measured with a Keithley 2400 SourceMeter in a four wire configuration connected via GPIB bus to the same computer.

The values of their room-temperature resistance vary from 1 to 10 kΩ at 35^o and 7^{o}C respectively. It was found that the resistance temperature behaviour of the α-$(BEDT\text{-}TTF)_2I_3$ -based covering layers dramatically depend on the treatment temperature (Fig.3) while their electromechanical properties does not depend on the temperature of the surface treatment. The temperature coefficient of resistance (TCR), calculated as a relative resistance change per grade ($TCR=\Delta R/(R_0\Delta T)*100\%$), was found to vary from -0.2 to 0.2 %/deg. Here R_0 is the sample resistance at room temperature, R is the sample resistance at high temperature T and $\Delta T=T-T(25\ ^oC)$.

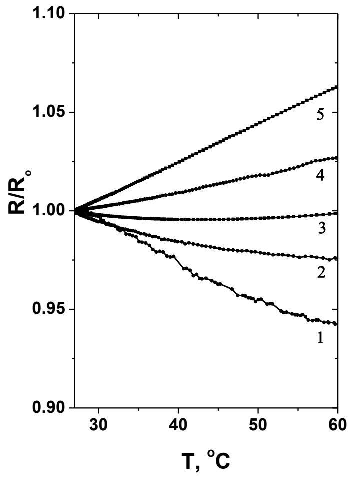

Fig.3 Resistance temperature dependence for films that were prepared at different temperatures (1 – 7ºC; 2 – 10ºC; 3 – 15ºC; 4 – 20ºC; 5 – 30ºC).

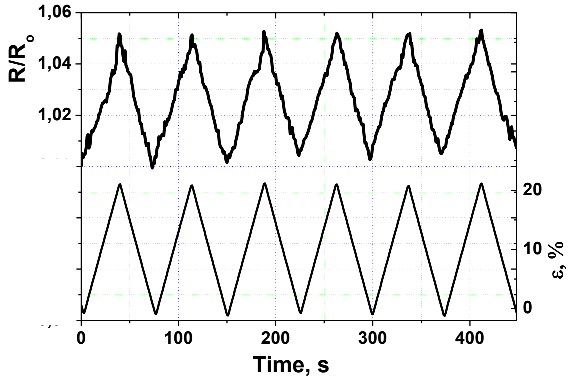

Fig. 4 Resistance changes with time for a 4 mm gauge length film (that was prepared at 15ºC) with a R_0=31.8 kΩ upon application of 6 cycles of 20 µm monoaxial elongations. Resistance and elongation data were measured every 0.5 s during the multi-cyclic deformations).

As shown in Fig. 4 the electrical response of the sensing BL film with TCR=0.05 %/deg. to monoaxial cyclic deformation is a well reproducible one, gauge factor being 10 (in order to compare the gauge-factor for conventional gauge-sensors based on Ni-Cu alloy is about 2). This result can be used to engineering strain sensors with low TCR that is of a great interest for many sensing technology.

Acknowledgements

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